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Effectiveness of Selected Soil Conservation Practices on Soil Erosion Control and Crop Yields in the Usambara Mountains, Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author SBM designed the study, wrote the protocol, conducted field work, performed statistical analysis, and wrote the first draft of the manuscript. Author BMM designed the study, conducted field work, managed the literature searches and edited drafts. Author PWM designed the study, conducted field work and edited drafts. Authors DNK, JD and JP designed the study and edited drafts. Authors IM and JS conducted field work. All authors read and approved the final manuscript.

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ABSTRACT

Indigenous soil conservation measures such as *miraba* have been widely used in Usambara Mountains for controlling soil erosion but with little success. On-farm runoff experiments were set from 2011–2014 on *Acrisols* in Majulai and Migambo villages with contrasting agro-ecological

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conditions in the Usambara Mountains, Tanzania. The aim was to investigate the effectiveness of *miraba* and *miraba* with various mulching materials in reducing runoff, soil and nutrient losses and improving productivity of maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Results show that mean annual runoff coefficients (mm mm^{-1}) ranged from 0.72 for cropland with no soil conservation measure (control) to 0.15 for cropland with *miraba* and Tithonia (*Tithonia diversifolia*) mulching in Majulai village and respectively from 0.68 to 0.13 in Migambo village. Soil loss was significantly (*P* = .05) higher under control than under *miraba* with either *Tughutu* (*Vernonia myriantha*) or Tithonia mulching e. g. 184 vs. 20 in Majulai and 124 vs. 8 Mg ha^{-1} $year^{-1}$ in Migambo village in 2012. The *P*-factors were significantly (*P* = .05) higher under *miraba* sole than under *miraba* with mulching in Majulai village (0.18 vs. 0.11) and in Migambo village (0.10 vs. 0.05).The annual nutrient losses in kg $ha^{-1}yr^{-1}$ were significantly (*P* = .05) higher under control than under *miraba* with mulching 367 vs. 37 total N, 0.8 vs. 0.1 P and 14 vs. 4 K for Majulai village; 474 vs. 26 total N, 0.7 vs. 0.1 P and 20 vs. 1.2 K for Migambo village in 2012. Maize and bean yields were significantly (*P* = .05) higher under *miraba* with *Tughutu* mulching than under control (*e.g.* 2.0 vs. 0.7 Mg ha^{-1} for maize in Majulai in 2012). Thus *miraba* with *Tughutu* mulching is more effective in improving crop yields than *miraba* with Tithonia and *miraba* sole.

Keywords: Runoff experiments; indigenous SWC; soil and nutrient losses; miraba, RUSLE; maize; beans.

1. INTRODUCTION

Soil erosion has been reported as a serious problem facing agricultural production all over the world [1-5]. Soil erosion by water is a major factor causing land degradation in the Usambara highlands of Tanzania and severely affects soil functions resulting in low crop productivity [6,7]. Soil erosion by water is defined as the detachment and displacement of soil particles by water, resulting in the development of rills and gullies [8]. To overcome the problem of soil deterioration, the Usambara farmers have developed local soil and water conservation (SWC) measures such as *miraba* (rectangular grass bound strips that do not necessarily follow contour lines [9]),micro-ridges and stone bunds as an integral part of their farming systems [7,9,10]. Most of the introduced measures have often been rejected or minimally adopted because such measures *e.g.* bench and *Fanya Juu* terraces (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along the contour lines at appropriate intervals depending on slope) were expensive in terms of labour and money, while also their promoters paid little attention on indigenous practices.

Miraba are widely practised by farmers in the Usambara Mountains. *Miraba* as a SWC measure is traditionally characterized by a wide spacing of grass strips across the slope and usually the spacing depends on the size of farm plots. For decades these SWC technologies were never a subject of scientific writing to allow improvements be made to effectively address problems of soil degradation and low crop productivity [10]. On the other hand, farmers have not been able to adjust these indigenous SWC techniques to rapidly changing farming systems and increasing intensity of land use [11,10].

On steep slopes like in Usambara Mountains, bench terraces are highly recommended as the most effective soil and water conservation measure in cropland [12,7,10,13]. However, due to low adoption rates in Usambara Mountains, the solution would be to improve and use indigenous SWC technologies such as *miraba* for sustained agricultural productivity in the area.

In the Usambara Mountains *miraba* are established by using either Napier or Guatemala grass. Grass strips forming *miraba* serve as barriers which capture soil particles that have been detached and transported with runoff from the cultivated land. Napier grass is mostly preferred because it is also used as forage for stall feeding, while Guatemala grass is appreciated for its drought resistance and to some extent is also used as for age for stall feeding.

Studies on effectiveness of some SWC technologies such as bench terraces, *Fanya Juu* terraces, grass strips [7,14] and *miraba* [15,16] on soil erosion control and agricultural productivity have recently been carried out in Western Usambara Mountains. However, the contribution of indigenous SWC technologies including *miraba* mostly practised in the study area have not fully been investigated for sustained agricultural productivity [10,15]. Moreover, it has been reported that establishment of *miraba* is far cheaper than the construction of bench terraces. Therefore efforts towards improving this technique are warranted [14,15,16].

Several erosion models are available to predict soil loss and to assess soil erosion risk [4,9]. However, RUSLE, the Revised Universal Soil Loss Equation [17] is widely used for estimating potential soil erosion by water especially at regional and national level because of its relative simplicity and robustness [4,18,16]. Likewise, this study applied RUSLE model to investigate the effectiveness of *miraba* and *miraba* with Tithonia (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*) mulching materials in reducing runoff, soil and nutrient losses using maize and beans as test crops. Specifically, the study intended to: (i) quantify soil and nutrient losses under selected soil conservation practices (ii) determine rainfall-runoff responses under selected soil conservation practices (iii) select the best soil conservation practice using the Revised Universal Soil Loss Equation (RUSLE) and (iv) determine the influence of selected soil conservation practices on crop yield.

2. MATERIAL AND METHODS

2.1 Description of the Study Sites

The study was conducted in Migambo and Majulai villages which represent different agro-ecological zones in Western Usambara Mountains, Lushoto District, Tanzania (Fig. 1) located between longitudes 38º15' to 38º24' E and latitudes 4º34' to 4º48' S. The area is highly dissected with steep slopes ranging from 20 % to over 50 % and altitude of about 1402 m.a.s.l.in Majulai and 1682 m.a.s.l. in Migambo village. Migambo is humid cold with mean annual air temperature of 12−17ºC and annual precipitation is 800–2300 mm [16]. Majulai is dry and warm with mean annual air temperature between 16 and 21ºC and annual precipitation of 500–1700 mm [13,16]. The monthly reference evapo-transpiration (ETo) as estimated by the local climate estimator software (New_LocClim) [19] ranges from 100 mm to 145 mm. Majulai and Migambo villages support a large population density of more than 120.4 persons/km^2 [20].

According to the World Reference Base (WRB) [21], the soil type in Majulai site classifies as *Chromic Acrisol* (*Humic, Profondic, Clayic, Cutanic, Colluvic*) whereas in Migambo site the soil is *Haplic Acrisol* (*Humic, Profondic, Clayic, Colluvic*). The main land uses include cultivation on slopes and in valleys, settlements on depressions, ridge summits and slopes and forest reserves on ridge summits and upper slopes. Vegetables such as carrots, onions, tomatoes, cabbages, and peas are grown as sole crops in valleys under rain fed or traditional irrigation. Beans are mainly grown during the long rainy season while maize is grown during the short rains. Round potatoes and fruits, namely peaches, plums, pears, avocado and banana are grown on ridge slopes under rain fed mixed farming. Round potatoes are also grown in valleys as sole crop or intercropped with maize.

2.2 *Miraba* Establishment in Runoff Experiments

Miraba were established by using Napier grass (*Pennisetum purpureum*) barriers in runoff experiments in April 2011 about nine months before data collection started. Napier grass barriers forming *miraba* were established by planting tillers in a single row at 10 cm spacing perpendicular to slope and were maintained to about 50 cm wide strips. In the current study Napier grass barriers across the slope were spaced 5 m apart to mimic the recommended maximum effective width of hand made bench terraces [12]. Along the slope the Napier grass barriers were set at 3 m apart. It has been documented that soil conservation measures such as *Fanya Juu* and stone bunds tend to progressively form bench terraces when they are at narrow spacing [12,22]. Moreover, the closer the grass strips are, the more effective they become [22]. Progressive bench terrace formation is also possible under *miraba* when adjusted to appropriate spacing of grass strips. Natural bench terrace formations as a result of *miraba* implementation are much less expensive compared to mechanical bench terrace construction. Bench terraces are highly recommended for use in Usambara Mountains [23,6,7,10].

2.3 Experimental Design

Closed runoff plots of 22 mx 3 m in a randomized complete block design (RCBD) were set along lower ridge slopes at 50 % slope in Majulai and

45% slope in Migambo village respectively. The plots were enclosed by *miraba* and bounded by pieces of wood that protruded 15 cm above the soil surface to prevent inflow and outflow from the plot borders. The pieces of wood were connected to three collector drums (each 220 litres) with hinged lids. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were planted inrotation as test crops in 2012 and 2013/14 rainy seasons. Maize was planted during short rains (*vuli*), while beans were planted during long rains (*masika*).The treatments included runoff plots (Fig. 2) with: (i) *Miraba* with maize or beans (*MI*) (ii) *Miraba* with *Tithonia* mulching and planted with maize or beans (*MITH)* (iii) *Miraba* with *Tughutu* mulching and planted with maize or beans (*MITG*) (iv) plots without SWC measure and planted with maize or beans (Control) (*CO*) (v) Bare plots (*BA*), all replicated three times. Mulching materials were the leaves of the readily available shrubs in both villages namely *Alizeti Pori* (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*). Tithonia has frequently been reported as a good green manure while also *Tughutu* is known to contain N, P and K [24,25,26]. Samples were collected from each mulching material for determination of total N, available P, K^+, Mg^{2+}, Ca^{2+} and Na^+.

2.4 Rainfall Data Collection

Daily rainfall was measured from 1st January 2012 to 16th February 2014 using standard rain gauges and tipping buckets with a CR10 data logger (Campbell Scientific, Logan UT) installed at the experimental sites in Migambo and Majulai villages.

2.5 Runoff, Sediment and Nutrient Loss Determination

Runoff and sediment was collected daily from 1st January 2012 to 16th February 2014. Beans were grown during the long rains, weeds were left to grow in the field during off season, and maize was grown in short rains. Runoff volume was estimated by measuring the depth of water in cm in the collecting drums and then converted to volume of water in litres. Sediment load was estimated by sampling water in collecting drums after vigorously stirring the suspension.

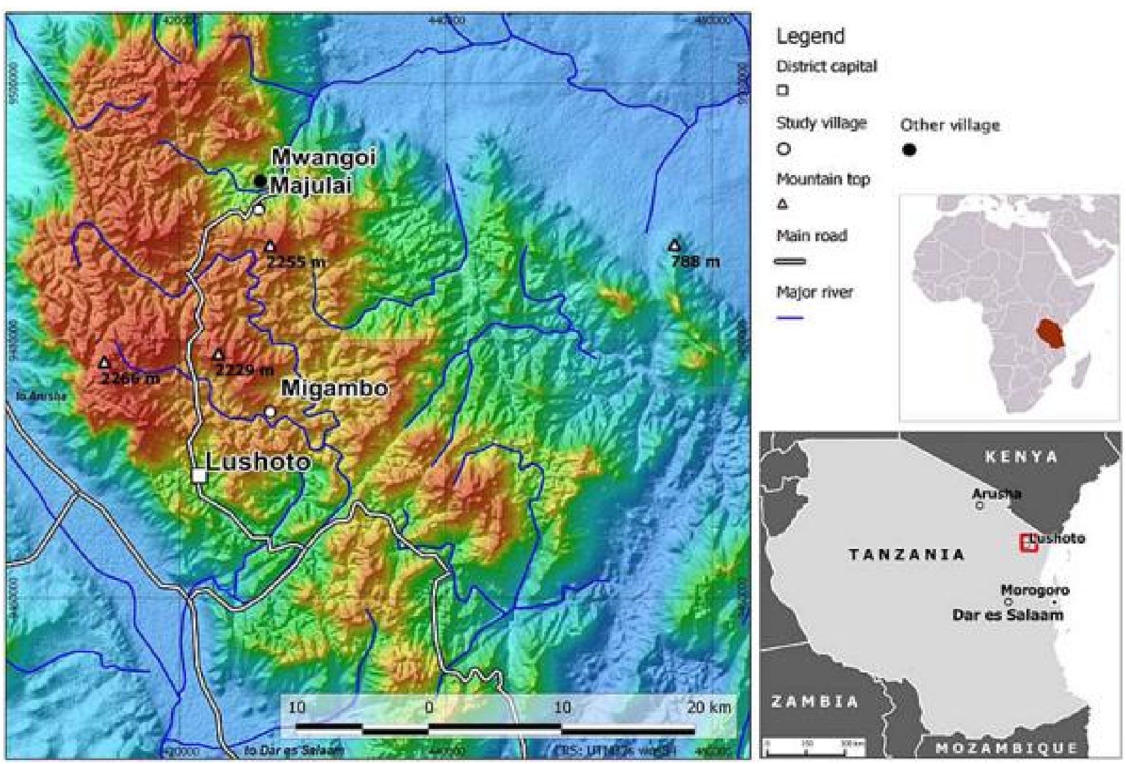

Fig. 1. Location map of Majulai and Migambo villages, Lushoto District, Tanzania. (Adapted from Msita, [16])

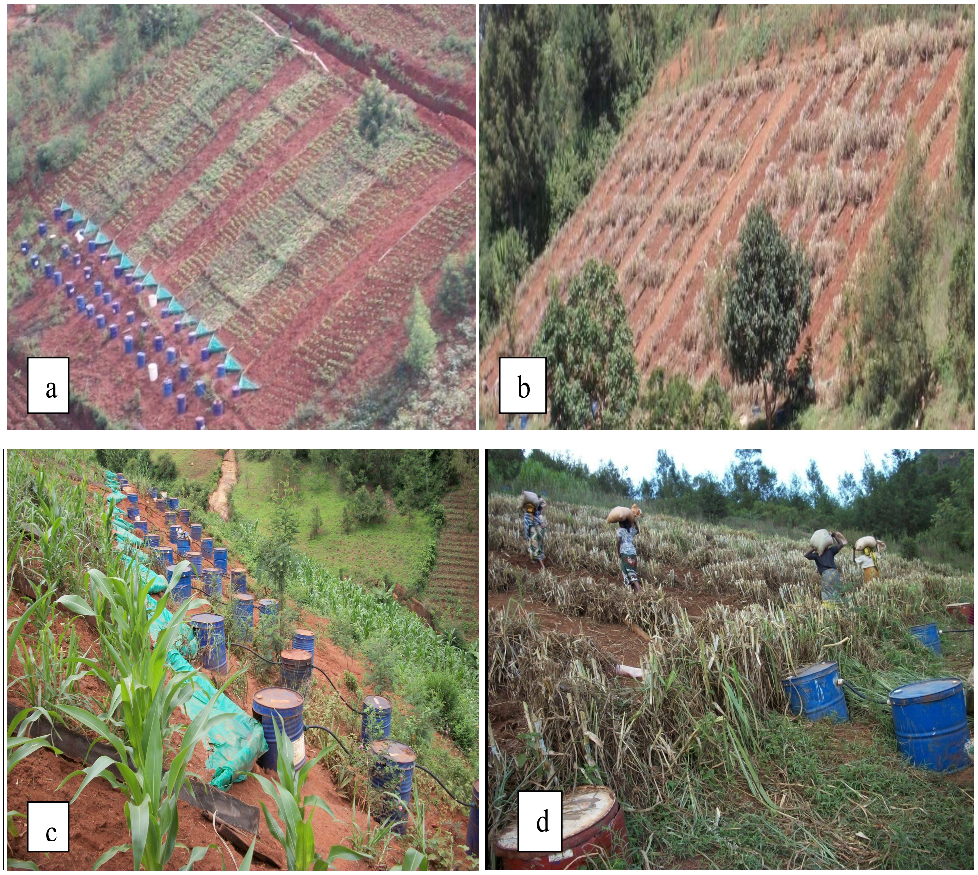

Fig. 2. Illustration of experimental plots a) Majulai plots layout b) Migambo plots layout c) Majulai plots with maize crop d) Migambo plots and application of farm yard manure

The water sampling was done by lowering a one litre plastic bottle from the water surface to the bottom of the drum, and samples of about 100 ml were collected at the bottom, middle and upper part when runoff depth in the drum was above 25 cm. Heavy sediments in the drums were scooped out, weighed and a 1 kg soil sample collected, oven dried for 24 hours at 105ºC and weighed for dry soil loss calculation. The suspended sediment samples were filtered using Whatman No. 42 filter paper and dried for 24 hours at 105ºC until constant weight was obtained [27] and the soil loss (Mg $ha^{-1}yr^{-1}$) was determined. Soil losses from heavy sediments and from suspended materials from each runoff event were added to compute total soil loss for the events. These losses were finally added to compute total soil loss per annum. The soil samples for nutrient loss determination were collected by decanting the suspended sediment in buckets.

In each runoff experimental site a soil profile was excavated and soil samples were collected from each horizon for pedological characterization. Undisturbed core soil samples were taken at 0-5 cm, 45-50 cm and 95-100 cm soil depth by Kopeck's core rings (100 cm^3) for bulk density, gravimetric moisture and available moisture determinations. The soil was classified to Tier-2 according to the World Reference Base for Soil Resources WRB [21].

2.6 Crop Yields

Maize (*Zea mays*) PAN 67 variety and beans (*Phaseolus vulgaris*) Kilombero variety were planted in runoff plots during the 2012 and 2013/14 rain seasons with maize in the short rains (*vuli*) and beans in the long rains (*masika*) at the recommended spacing of 30 cm within rows and 75 cm between rows for maize and 25 cm within rows and 50 cm between rows for beans. Beans were always planted one month before the maize was harvested in Migambo and two weeks before harvesting maize in Majulai village. Farmyard manure with 1.7% N, 0.4% P and 1.9% K was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, diammonium phosphate (DAP) 18: 46: 0 NPK ratio and Urea 46% N were applied at the rate of 80 kg ha^{-1}, but Urea was not applied for beans. At maturity maize and bean grains were harvested and dried to about 13% moisture content.

2.7 Soil Analysis

Soil analysis was done following Moberg's [28] Laboratory Manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^+ and K^+ by flame photometer and pH water by normal laboratory pH meter.

2.8 Determination of the RUSLE Factors

The RUSLE equation expresses average annual soil loss Mg ha^{-1} $year^{-1}$ caused by sheet and rill

erosion [17];

$$A = RKLSCP \quad (1)$$

Where A is the long term average soil loss (Mg ha^{-1} $year^{-1}$), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), K is the soil erodibility factor (Mg ha MJ^{-1} mm^{-1}), LS is dimensionless factor combining slope steepness(S) and slope length (L), C and P are dimensionless factors accounting respectively for crop cover and management and conservation practices. The equation developed by Vrieling et al. [29] was used to calculate Rfactor. Such that $R = 50.7$

$$MFI – 1405 \quad (2)$$

Where MFI is the Modified Fournier Index

calculated from

$$MFI = \sum_{n=1}^{\infty}(p^2)/\mathrm{P} \quad (3)$$

Where p is the average monthly rainfall (mm) and P is the average annual rainfall (mm).In the absence of any cover crop or soil protection measure, as for the bare plot, C and P factors are equal to 1. Thus K factor was calculated from

$$K = A_{\text{bare plot}}/(RLS) \quad (4)$$

According to Mitchell and Bubenzer [30], LS = $[0.065 + 0.0456s + 0.006541s^2]$ x

$$(l/22)^{1/2} \quad (5)$$

Where: s, is the slope gradient in %; l, is the plot length in m; constant ½, is used where slope steepness is ≥ 5%

The effectiveness of soil conservation practices on reducing soil loss was determined by the use of C and P factors when compared to the bare plots. The C factor in the long rain season was a function of the bean crop cover; in the off season the C factor was determined by weed cover, while in the short rains maize cover was considered. The C factor was calculated as the ratio between the seasonal or annual soil losses of the control plot to the seasonal or annual soil losses of the bare plot. The P factor was calculated as the ratio between the seasonal or annual soil losses under *miraba* plots to the seasonal or annual soil losses under control plots.

$$C(CO\text{ plot}) = A(CO\text{ plot}) / A(BA\text{ plot}) \quad (6)$$

$$P(MI\text{ plot}) = A(MI\text{ plot}) / A(CO\text{ plot}) \quad (7)$$

$$P(MITH\text{ plot}) = A(MITH\text{ plot}) / A(CO\text{ plot}) \quad (8)$$

$$P(MITG\text{ plot}) = A(MITG\text{ plot}) / A(CO\text{ plot}) \quad (9)$$

Where: $A(CO$ plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under control plots; $A(BA$ plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under control plots; A *(MI, MITH* and *MITG plot),* are respectively the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under *miraba*, *miraba* with Tithonia mulching and *miraba* with *Tughutu* mulching. The effectiveness of soil conservation practices on reducing soil loss was determined by the percent of C and P factors with reference to bare plots. The effectiveness of soil conservation practices on reducing nutrient losses was also calculated in percentages in respect of bare plots.

2.9 Statistical Analysis

Bartlett's test for homogeneity of variance was conducted to test data normality using GenStat software [31]. The relationships between daily rainfall and daily runoff were determined by

Linear Regression Analysis with threshold runoff values obtained from the X-axis intercept. Analysis of Variance (ANOVA) in Gen Stat statistical software [31] was performed where Least Significant Difference ($LSD_{0.05}$) was used to detect mean differences between treatments.

3. RESULTS AND DISCUSSION

3.1 Rainfall Erosivity between the Two Villages with Contrasting Climatic Conditions

The annual and seasonal rainfalls recorded during the two consecutive years are presented in Table 1, while rainfall distribution in Fig. 3. It can be seen that, as the rainfall depth was higher in Majulai village than Migambo village in 2012, rainfall erosivity *R* factor was also higher in Majulai, while in 2013 higher values of rainfall depth and *R* factor were observed in Migambo village (Table 1).

3.2 Soil loss in Relation to SWC Measures in the Two Villages with Contrasting Climatic Conditions

From our results (Table 1), Majulai village had significantly (P<.001) higher annual soil losses than Migambo in 2012, but in 2013 annual soil losses weresignificantly (P<.001) higher in Migambo than in Majulai village. The difference in soil losses between the two villages can partly be attributed to the rainfall depth (Table 1), as it can clearly be seen that the higher the rainfall depth the higher the soil losses in the studied villages. Similar observations were reported by Kabanza et al. [32], where soil losses in Makonde plateau were much higher than in in land plains and rainfall depth was spotted as the main contributing factor. The relatively steeper slopes in Majulai than in Migambo could also explain the soil loss differences. This is supported by the work of Liu et al. [33] where slope gradients were found to be strong determinants of soil loss. On the other hand, soil losses differed significantly (P<.001) between SWC measures in both villages. Soil losses followed the trend: bare plots > cropl and with no SWC measures > cropl and with *miraba* sole > cropl and with *miraba* and Tithonia or *Tughutu* mulching. The reduced soil losses under *miraba* and *miraba* with mulches could be explained by the effect of grass barriers forming *miraba* that captured some soil sediments that were with runoff. This observation is also supported by Wanyama et al. [34] who reported grass strips to effectively trap more than 70% sediments under natural rainfall. Besides, *miraba* were progressively forming bench terraces such that the terrace height reached about 1m in Migambo and 0.7 m in Majulai village after two years of experimentation. The terraces so formed reduced the slope steepness, thereby resulting reduced runoff velocity and increased rate of infiltration. This ultimately reduced runoff volume and sediment losses. Similarly, mulches also reduced runoff velocity, thereby increasing rate of infiltration and reducing runoff volume and sediment losses.Such observations were also reported by Bajracharya et al. and Tiwari et al. [35,36] in Nepal where mulching was found to reduce annual soil loss by 60 to 90% in maize–mustard cropping system as compared to conventional farmers' practices.

3.3 Rainfall-Runoff Responses under Selected Soil Conservation Practices

The slope of the regression line was used as a measure of the rainfall-runoff response. The rainfall-runoff response varied between the villages and between soil conservation measures (Fig. 4a). The differences can be explained by the influences of the studied soil conservation measures; bare plots had the highest annual runoff coefficient, while *miraba* with Tithonia and *miraba* with *Tughutu* mulching had the lowest (Table 2 & Fig. 4). The rainfall threshold values to initiate runoff varied between the soil conservation measures and between the studied villages. These differences were also directly associated with the effects of soil conservation measures and the differences in climatic conditions between the villages (Fig. 3). The rainfall threshold values to initiate runoff follow the trend: *miraba* with Tithonia and *miraba* with *Tughutu* mulching > *miraba* sole > cropl and with no SWC measures > bare land in both villages. *Miraba* with mulching had the highest rainfall threshold values *i.e.* 5.0 mm in Migambo village and lowest values under bare land *i.e.* 3.4 mm in Majulai village. The observed rainfall threshold values are very low implying that the soils of Usambara Mountains are very sensitive to runoff and therefore to soil loss. Thus implementation of improved *miraba* with mulching could be a very effective way to curb soil degradation by water erosion in the area.

3.4 Effectiveness of Selected Soil Conservation Practices in Relation to RUSLE Factors

The relative effectiveness of selected soil conservation practices with reference to soil losses from cropl and with no SWC measures are presented in Fig. 5. It can clearly be seen that *miraba* sole, *miraba* with Tithonia and *miraba* with *Tughutu* mulching were more effective in reducing soil loss in Migambo than in Majulai village. This can be attributed to the differences in rainfall distribution where the poor rainfall distribution in Majulai village (Fig. 3) causes Napier grass in the *miraba* to die during dry spells, while the reliable rainfall in Migambo makes Napier grass barriers that form *miraba* to persist throughout the year and thus form denser grass strips than in Majulai village. It is evident from Fig. 4 that *miraba* reduced soil losses by about 80% in Majulai and 90% in Migambo village relative to soil losses from cropland with no SWC measures. On the other hand *miraba* with Tithonia and *Miraba* with *Tughutu* mulching reduced soil losses by 90% in Majulai and 95% in Migambo village relative to soil losses from cropl and with no SWC measures (Fig. 5).

Based on the work by Kabanza et al. [32] RUSLE factors were found to provide better insight than other attributes when assessing the effectiveness of soil conservation measures. The observed *K* factors were 0.0016 (Mg h MJ^{-1} mm^{-1}) for *Chromic Acrisol* in Majulai and 0.0018 (Mg h MJ^{-1} mm^{-1}) for *Haplic Acrisol* in Migambo village (Table 4). The observed *K* factor values are very low, indicating high susceptibility of the studied soils to erosion. More erodible soils such as silt loams have their *K* factor values ranging from 0.03 – 0.05(Mg h MJ^{-1} mm^{-1}) [37,38]. The *P* factor values are much higher in Majulai than in Migambo village (Table 3 & 4) indicating that the studied soil conservation practices have stronger effect in Migambo than in Majulai village. This can be explained by the good rainfall distribution in Migambo as compared to Majulai village which experiences long dry spells (Fig. 3) resulting natural death of *miraba* Napier grass, thus, reducing its effectiveness. Similarly significant differences were observed between soil conservation practices where *miraba* with Tithonia and *miraba* with *Tughutu* mulching were more effective in reducing soil loss than *miraba* sole and control (plots with maize or bean crop). This is due to the fact that grass barriers forming *miraba* and mulches tend to reduce runoff speed there by increasing the rate of infiltration. This tendency was also reported by Dur'an et al. [39], Reubens et al. [40], Wanyama et al. [34] and Birru et al. [41]. The most effective soil conservation practices in both villages are thus *miraba* with Tithonia and *miraba* with *Tughutu* mulching (*P*=0.11 for Majulai and *P*= 0.002 for Migambo village).

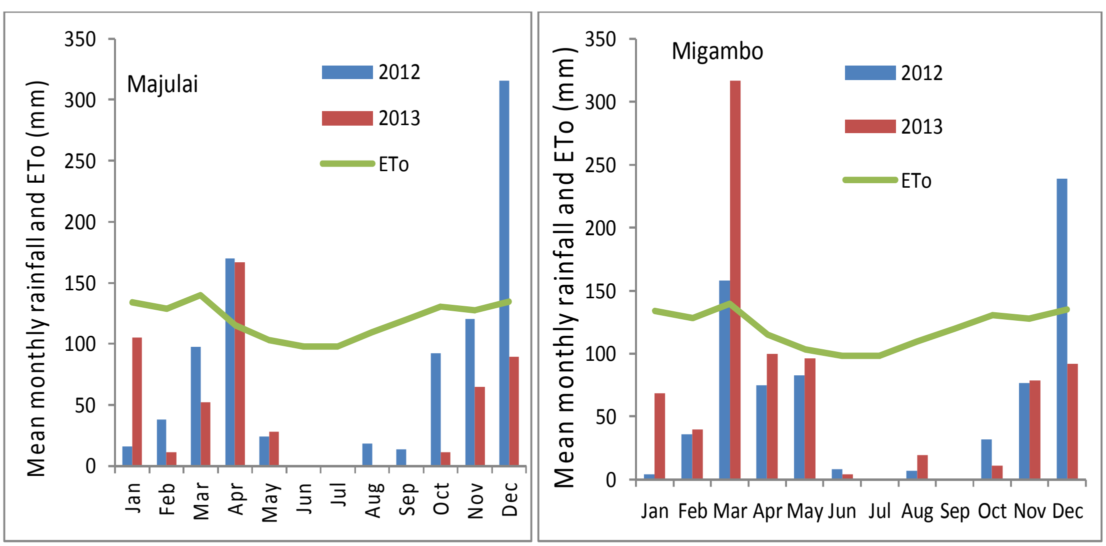

Fig. 3. Rainfall distribution in Majulai and Migambo villages and estimated reference evapo-transpiration (ETo) measured during 2012 and 2013; ETo determined according to New_LocClim estimator; [19]

Table 1. Rainfall and annual soil losses measured in Majulai and Migambo villages Lushoto District, Tanzania

			Majulai		Migambo	
			2012	2013	2012	2013
Rainfall (mm)						
	Long rains (Feb.- May)		329.3	258.0	359.4	552.1
	Offseason rains (Aug – Sept.)		28.7	0	7.1	23.4
	Short rains (Oct. – Jan.)		636.9	165.1	415.8	222.7
	Annual		906	528	718	826
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)			7774	3857	5859	7247
			Majulai		Migambo	
Soil loss Mg ha^{-1} $year^{-1}$			2012	2013	2012	2013
	Bare plots	Replicates				
		1	254.6	100.6	175.6	177.1
		2	262.7	107.9	182.0	188.3
		3	266.9	105.7	183.6	186.6
		Mean	261.4	104.7	180.4	184.0
	Plots with maize or beans	1	179.6	72.9	124.1	133.3
		2	183.3	76.8	124.3	129.8
		3	187.8	77.2	124.4	131.6
		Mean	183.6	75.6	124.3	131.6
	Miraba with maize or beans	1	34.7	12.2	13.3	14.9
		2	35.9	11.7	13.4	13.4
		3	33.6	14.3	13.5	14.3
		Mean	34.7	12.7	13.4	14.2
	Miraba with Tithonia and maize or beans	1	17.58	5.42	8.02	5.30
		2	20.03	8.20	7.58	4.76
		3	20.05	9.09	7.97	5.18
		Mean	19.22	7.57	7.86	5.08
	Miraba with *Tughutu* and maize or beans	1	18.47	5.62	7.97	5.47
		2	20.10	9.34	7.43	5.18
		3	20.02	9.33	7.24	5.27
		Mean	19.50	8.10	7.55	5.31
	LSD (*P* = .05)		4.14	4.06	4.14	4.06
	SE		1.39	1.37	1.39	1.37

LSD: least significant different; SE: standard error of means

Table 2. Daily runoff (mm) (Y) response to daily rainfall (mm) (X) for Majulai and Migambo villages in Usambara Mountains, Tanzania

Village/Treatments	Regressions equations	Runoff thresholds	R^2	No. of rainfall incidences	No. of runoff observations
Majulai					
Bare plots	Y=0.230X-0.79	3.4	0.87	118	353
Control	Y=0.190X-0.72	3.8	0.81	118	353
Miraba	Y=0.065X-0.26	4.0	0.66	118	353
Miraba+Tithonia	Y=0.038X-0.15	4.2	0.51	118	353
Miraba+Tughutu	*Y=0.037X-0.16*	*4.2*	0.52	118	353
Migambo					
Bare plots	Y=0.200X-0.76	3.8	0.93	122	365
Control	Y=0.160X-0.68	4.3	0.92	122	365
Miraba	Y=0.040X-0.19	4.7	0.81	122	365
Miraba+Tithonia	Y=0.030X-0.13	5.0	0.91	122	365
Miraba+Tughutu	Y=0.027X-0.15	4.9	0.89	122	365

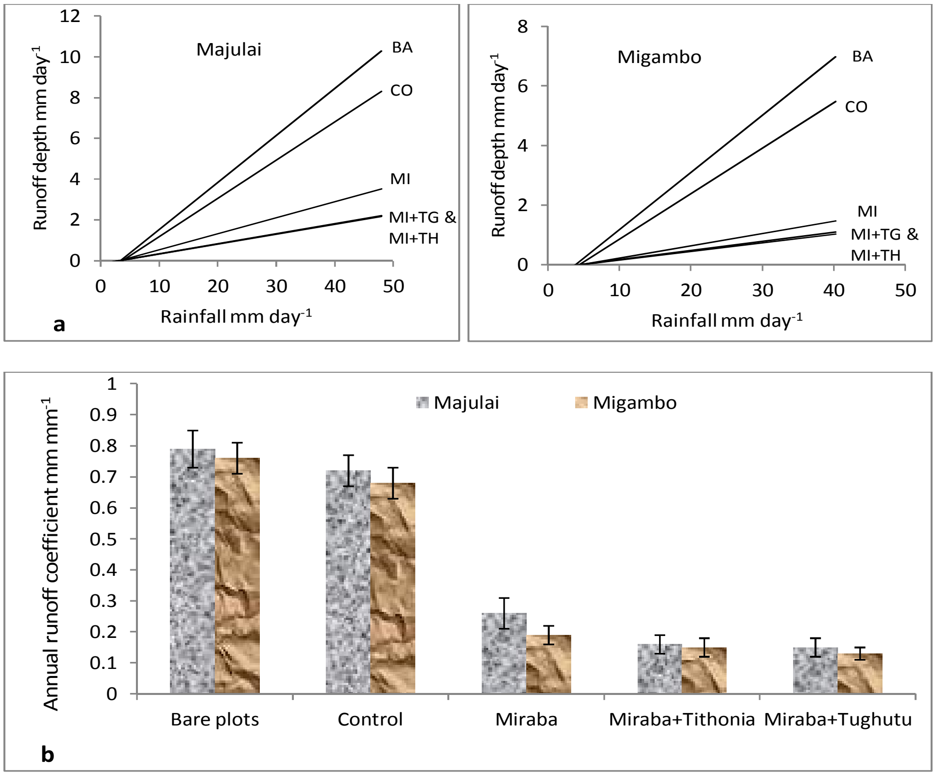

Fig. 4. a) Rainfall-runoff response curves b) runoff coefficients for different soil and water conservation measures in Usambara Mountains, Tanzania. (Key: BA= Bare plots; CO= Control; MI= *Miraba* sole, MI+TG= *Miraba* with *Tughutu* mulching and MI+TH= *Miraba* with Tithonia mulching)

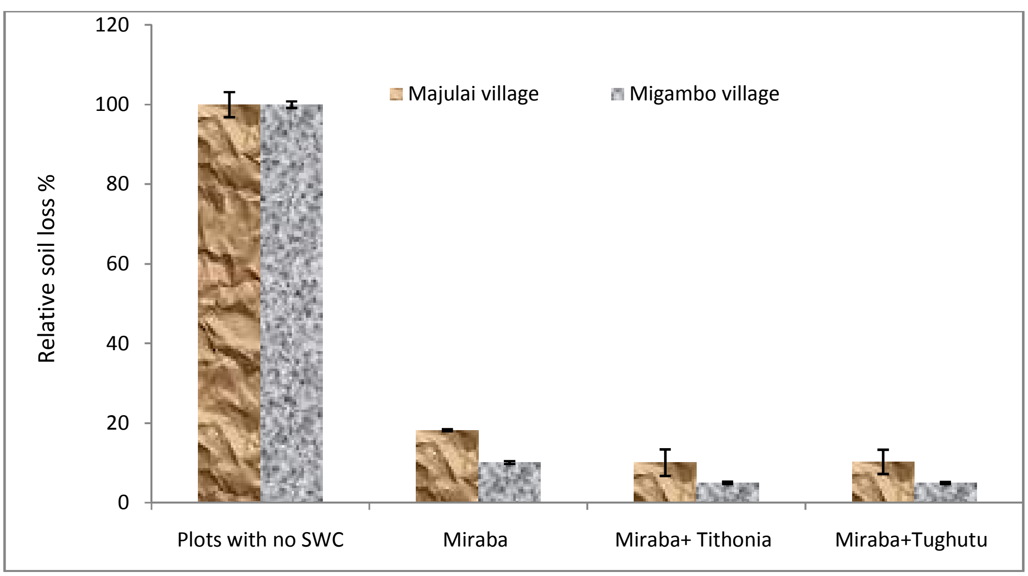

Fig. 5. The mean relative soil loss with STDEV from 3 replicates under the studied soil conservation practices in Majulai and Migambo villages

Table 3. RUSLE factors for the Majulai and Migambo villages in Usambara Mountains, Tanzania based on soil loss measurements on runoff plots in 2012 and 2013

			Majulai		Migambo		
RUSLE factors		**n**	**2012**	**2013**	**2012**	**2013**	**Sign.**
R (MJ mm ha^{-1} h^{-1} year^{-1})		1	7774	3857	5859	7247	ns
K (Mg h MJ^{-1} mm^{-1})		1	0.0018	0.0015	0.0020	0.0017	ns
C (dimensionless)	Maize and beans	3	0.71	0.70	0.70	0.70	ns
P (dimensionless)							
	Miraba	3	0.19	0.17	0.10	0.10	***
	Miraba+Tithonia	3	0.11	0.10	0.06	0.04	***
	Miraba+*Tughutu*	3	0.11	0.10	0.06	0.04	***
	LSD (*P* = .05)		0.03	0.03	0.03	0.03	

*LSD: least significant different; Sign.ns: not significant; ***: P<.001. Mann-Whitney U test for R, K and C factors; Nested ANOVA for P variables*

Table 4. RUSLE factors for the Majulai and Migambo villages in Usambara Mountains, Tanzania based on soil loss measurements on runoff plots from 2012-2014 rain seasons

		Majulai			Migambo			
RUSLE factors		Median	IQR	n	Median	IQR	n	Sign.
R (MJ mm ha^{-1} h^{-1} yr^{-1})		5816	1958	2	6553	694	2	ns
K (Mg h MJ^{-1} mm^{-1})		0.0016	0.0002	2	0.0018	0.0002	2	ns
C (dimensionless)		Mean	STDEV		Mean	STDEV		
Beans/weed/Maize		0.71	0.02	6	0.70	0.005	6	ns
P(dimensionless)		Mean	STDEV		Mean	STDEV		
	Miraba	0.18	0.002	6	0.10	0.003	6	***
	Miraba+Tithonia	0.11	0.03	6	0.05	0.002	6	***
	Miraba+*Tughutu*	0.11	0.02	6	0.05	0.002	6	***
	LSD (*P* = .05)	0.03			0.03			

*LSD: least significant different; IQR: inter-quartile range; STDEV: standard deviation; n: number of observations; Sign. ns: not significant; ***: P<.001. Friedman test for R, K and C factors; Nested ANOVA for P variables*

3.5 Soil Nutrient Losses under the Studied SWC Measures

Soil nutrient losses under soil conservation practices are presented in Fig. 6. Soil nutrient losses were significantly (*P*<.001) different between SWC practices. The differences in soil nutrient losses can directly be associated with the effects of soil conservation practices (Table 5). Soil losses followed the trend: Bare plots > cropl and with no SWC measure (control) > cropl and with *miraba* sole > *miraba* with *Tughutu* and *miraba* with Tithonia mulching (Table 5). Similarly Msita [16] in Migambo village, Tanzania reported lower losses of total N, P and K^+ in plots with *miraba*, farmyard manure and Tithonia mulching than in cropl and with no SWC measures.

The relative effectiveness of soil conservation practices with reference to soil losses from cropland with no soil conservation measures are presented in Fig. 6. There are obvious differences in soil nutrient loss control between soil conservation measures. It is clear that *miraba* with mulching reduced soil nutrient losses by about 95% in Migambo and 85% in Majulai village, while *miraba* sole reduced nutrient losses by 90% in Migambo and about 80% in Majulai village (Fig. 6).

3.6 Impact of Selected Soil Conservation Practices on Crop Productivity in the Two Studied Villages

The yields of maize and beans are presented in Table 6. The results show that there is a significant (*P*=.05) difference in crop yields between selected soil conservation practices and between the two studied years in both villages. In Majulai village maize grain yields were higher under *miraba* with *Tughutu* mulching than under *miraba* with Tithonia, *miraba* sole and control in 2012, but there was no maize yield in 2013 due to drought. The trend of bean grain yields followed the trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control. The trend was similar in Migambo village where *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control for both maize and bean grain yields (Table 6). Maize grain yields were significantly (P = .05) higher in 2013 than in 2012, but there were no significant (P=.05) differencesv in bean grain yields between the two years of study except under *miraba* with Tithonia and *miraba* with *Tughutu* in Majulai village. There were also some differences in maize and bean yields between the two villages, with higher yields in Migambo than in Majulai (Table 6). The observed crop yields under the studied SWC practices (Table 6) were higher than the average yields according to FAO [42] of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania. It is clearly observed that the crop yield differences are highly influenced by the SWC practices (Table 6) and could partly be explained by differences in climatic conditions of the two villages. The rainfall in Majulai is unreliable while Migambo village experiences reliable rainfall with a fair distribution during the growing seasons (Fig. 3).

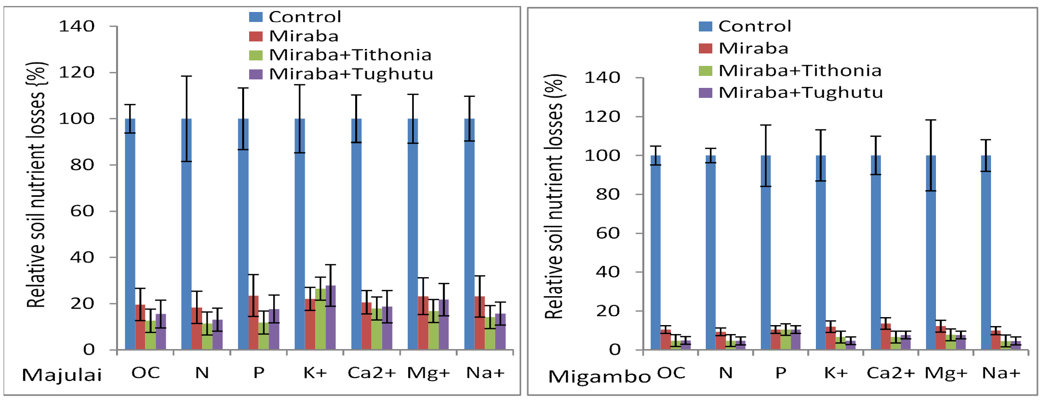

Fig. 6. The mean relative nutrient loss under the studied soil conservation practices in Majulai and Migambo village

Table 5. Soil nutrient loss (kg ha^{-1} $year^{-1}$) under the studied soil conservation practices in the two villages

Village (year)	Treatments	n	OC	N	P	K^+	Ca^{2+}	Mg^{2+}	Na^+
Majulai									
	Bare	72	4835.7	478.8	1.0	41.3	80.2	18.0	15.5
	Control	72	3049.7	306.5	0.8	13.6	62.7	18.3	8.8
	Miraba	72	632.7	59.2	0.2	2.7	12.8	4.0	2.3
	Miraba+Tithonia	72	414.7	36.6	0.1	3.8	8.2	2.9	1.4
2012	*Miraba+Tughutu*	72	518.3	42.5	0.1	4.1	11.5	4.0	1.5
	Bare	46	2024.3	176.3	0.7	5.9	23.9	8.4	6.5
	Control	46	1496.7	125.7	0.9	6.8	25.9	8.4	4.6
	Miraba	46	260.7	20.3	0.2	1.8	5.5	2.2	0.8
	Miraba+Tithonia	46	158.7	12.6	0.1	1.6	7.7	1.6	0.5
2013	*Miraba+Tughutu*	46	187.7	13.9	0.2	1.6	5.1	1.8	0.6
Migambo									
	Bare	51	6092.3	548.0	0.8	12.0	371.1	57.2	11.3
	Control	51	4908.7	474.3	0.7	19.7	262.1	46.3	8.8
	Miraba	51	450.0	40.7	0.1	1.9	30.7	4.9	0.8
	Miraba+Tithonia	51	251.7	27.2	0.1	1.7	20.3	4.5	0.5
2012	*Miraba+Tughutu*	51	276.7	26.0	0.1	1.2	20.2	4.3	0.5
	Bare	71	6308.7	525.4	1.2	15.9	437.6	74.4	12.6
	Control	71	4418.0	421.6	1.2	19.7	266.8	49.8	8.4
	Miraba	71	531	43.8	0.1	2.8	41.1	6.8	0.9
	Miraba+Tithonia	71	192.7	15.8	0.1	0.9	14.5	3.0	0.3
2013	*Miraba+Tughutu*	71	183	16.4	0.1	0.7	15.4	3.1	0.3

Table 6. Impact of selected soil conservation practices on crop yields in Majulai and Migambo villages

Village	SWC measures	N	Mean crop grain Yields (Mg ha^{-1}) in 2012		Mean crop grain Yields (Mg ha^{-1}) in 2013		
			Maize	**Beans**	**Maize**	**Beans**	**LSD (*P* = .05)**
Majulai							
Plots with no SWC		3	0.71	0.59	0.0	0.59	0.15
Miraba sole		3	1.26	0.81	0.0	0.85	0.15
Miraba with Tithonia		3	1.62	0.89	0.0	1.04	0.15
Miraba with *Tughutu*		3	1.97	0.93	0.0	1.09	0.15
LSD (*P* = .05)			0.15	0.15	0.0	0.15	
SE.			0.05	0.05		0.05	
Migambo							
Plots with no SWC		3	1.57	0.64	1.64	0.67	0.41
Miraba sole		3	2.58	0.81	3.12	0.92	0.41
Miraba with Tithonia		3	3.18	0.90	4.05	1.06	0.41
Miraba with *Tughutu*		3	3.79	0.95	4.83	1.14	0.41
LSD (*P* = .05)			0.41	0.41	0.41	0.41	
SE			0.14	0.14	0.14	0.14	
Majulai * Migambo							
LSD (*P* = .05)			0.32	0.32		0.12	
SE			0.11	0.11		0.04	

LSD: least significant different; SE: standard error of means

In 2012, the average maize yields in Majulai village in creased by 177% under *miraba* with *Tughutu*, 128% under *miraba* with Tithonia and 78% under *miraba* sole while there were no maize yields in 2013 due to drought. Bean grain yields in 2012 and 2013 respectively increased by 58% and 85% under *miraba* with *Tughutu*, 51% and 76% under *miraba* with Tithonia and 37% and 44% under *miraba* sole when compared with control. In Migambo village during the same period the average maize yields increased by 149% and 195% under *miraba* with *Tughutu*, 109% and 147% under *miraba* with Tithonia and 70% and 90 % under *miraba* sole when compared to control. Studies by Msita [15, 16] reported increased maize yields by 57 % under *miraba* as compared to control in Migambo village, while bean yields did not differ and the maize yield differences were associated with improved soil properties due to the effects of *miraba.*

Bean grain yields in 2012 and 2013 respectively increased by 48% and 70% under *miraba* with *Tughutu*, 41% and 58% under *miraba* with Tithonia and 27% and 37% under *miraba* sole when compared with control. It is clear that soil conservation measures contribute to higher crop yields by reducing the loss of plant nutrients and assuring better water supply to the crop. The study by Wickama et al. [13] in Usambara Mountains observed the average maize and bean yields of 270% and 583% higher in well managed farms with good quality terraces, well maintained grass strips, good quality seed for crops, adequate use of manure or fertilizer as compared to the control *i.e.* the farms with no terracing, no grass strips, use of local seed material, little use of manure and no use of fertilizer and no tree cover. The yield differences were reported to be influenced by the sustainable land management categories studied.

4. CONCLUSIONS AND RECOMMENDATIONS

Rainfall erosivity *R* and soil erodibility *K* factors did not differ significantly between the studied villages. Soil loss was significantly (*P* = .05) higher under cropl and with no soil conservation measures (control) than under *miraba* with mulching. The *P* factors were significantly (*P* = .05) higher under *miraba* sole than under *miraba* with mulching. The annual nutrient losses were significantly (*P* = .05) higher under control than under *miraba* with mulching. Maize and bean yields differed significantly (*P* = .05) between soil conservation practices in the following order: *miraba* with *Tughutu* mulching >*miraba* with Tithonia mulching >*miraba* sole >control. Whereas *miraba* with either *Tughutu* or Tithonia mulching showed greater potential in reducing soil and nutrient losses than *miraba* sole, *miraba* with *Tughutu* mulching was more effective in improving crop yields than *miraba* with Tithonia and *miraba* sole. Despite that the soils of Usambara Mountains are susceptible to erosion, the *C* and *P* factors indicate that these soils are responsive to soil conservation measures. More local shrubs and grasses should be investigated for use as both green manure and soil conservation measure under *miraba*. Further research needs to be conducted to investigate effectiveness of the studied soil conservation practices on waters hed to mitigate river stream sedimentation. It is strongly recommended that Tithonia and *Tughutu* shrubs be planted in the borders of the farm plots along the slope for easy availability. It is also recommended in Majulai village that drought resistant grasses such Guatemala be used for establishing *miraba* since Napier grass which is mostly preferred for fodder is sensitive to drought.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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